REVIEW ARTICLE

Agroforestry systems in the tropics: A critical review

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In scientific agricultural practices, agroforestry systems are gaining wide recognition due to its healthy integration of woody perennial trees, herbaceous crops and livestock's in unit areas which are socially acceptable, economically viable and ecologically sound. In the tropics, agroforestry system has been well established practice varies significantly from region to region depending on the levels of management inputs, structure and function of woody perennials, as well as environmental and ecological fitness of the system. The most common practices in the tropics includes; improved fallow, alley cropping, multifunctional trees on farms and rangelands, home gardens, windbreak, shelterbelts, silvopastoral grazing system, taungya farming and shaded perennial-crop system. The above-mentioned system has been well known for its potential in improving and sustaining agricultural production through increased soil fertility, climate change amelioration, breaking the current challenge of food insecurity and poverty circles, besides raising the livelihood of rural poor owing to diverse products derived from the systems such as food, fuel wood, timber and source of income. Poor policy, ineffective governance, less adoptability of systems by farmers due to unawareness is the major constraints behind success of agroforestry systems. In this context, a better and effective R&D along with scientific management of agroforestry practices not only promotes agroforestry systems but also promise better resource conservation along with maintaining soil-food-climate security at global scale.

Key Words: *Agroforestry; Climate change; Shelterbelts; soil; Resource conservation*

INTRODUCTION

The practice of integrating trees and shrubs (woody vegetation) with agronomic crops and/or animals is done deliberately for both economic and ecological benefits derived from their interactions Burgess and Rosati [1]. Hence, an agroforestry system is an interconnecting network of woody vegetation with crops and/or animals that work together Jhariya et al., Raj et al. [2]. There are large temporal differences in the growth and development of the woody component in an agroforestry system and the crop and/or animal component Burgess et al. [3]. The time frame between planting a tree and it reaching maturity can be 20–100 years whereas an annual crop and some animals can reach maturity in months. Hence the growth periods for the trees and the crops and livestock in agroforestry systems are substantially different. This diversity in the range of time, and also spatial, scales and the typically non-linear ways in which the components interact mean that agroforestry is a 'complex' system Boulton et al. [4]. Interestingly, for millennia, agroforestry has been extensively practiced to foster agricultural production around the world where available resources such as light, water and nutrients are efficiently utilized and recycle among the multifunctional systems of agricultural production [5].

The agroforestry system in the tropics can be traced back around 5000 years ago in China and other Asian countries, when the hunter gatherer realized that more animals are attracted when browsed resistant wild trees are planted in the wild grassland. Similarly, if the trees are felled, other herbaceous vegetation with nutritional value emerged and when the trees are burnt, the composition of this vegetation turns to be different. Hence it is taught that agroforestry and agricultural practices originated at the same time [6]. Notwithstanding, the recent dramatic reduction in tree cover due to unprecedented rise in human populations, in the tropical regions, trees remain key element for most landscape of human habitat [7]. However, the arrangement and management practices of the components in agroforestry system depend on the planned goals to be achieved. Farmers in west African savanna for example, the park-like landscape formed is due to valuable species of trees they maintained surrounding their fields that are quite resistance to periodic fire [8]. Tree crops like tea, coffee and cocoa reduced the impacts of pests and diseases pressure, crops' nutrients requirements as well as climatic extreme through maintenance and/or establishments of shade trees [9]. Generally, quite a lot of agroforestry practices can be grouped under different system such as parklands and alley cropping (silvoarable systems), montados and dehasas (silvopastoral systems), shelterbelts, riparian buffers and windbreaks (protective systems), home gardens (multistorey systems), shifting cultivation and rotational woodlots [10]. In addition to benefits derived through integrated system and environmental services like soil fertility improvement, erosion control, enhanced water availability, increased biodiversity and improved aesthetics of agricultural landscape, these system plays a vital role in food security providing agronomic crops, animal fodder, and timber/firewood [11].

The present review elucidates on the tropical agroforestry system for their social, economic and environmental benefits derived from the system along with the constraints and government policies that plays a key role for the awareness and efficient utilization of resources in the agroforestry practices, in line with the available scientific literatures.

AGROFORESTRY: A GLOBAL OVERVIEW

Increasingly, agricultural and forestry landowners in many countries are pursuing an integrated model on the same land due to comprehensive land management system that emphasizes a productive interdependent relationship between trees, agricultural crops and/or livestock. The feature of agricultural landscape is believed to be agroforestry throughout the world, although the practices from region to region vary significantly [12]. In improving land management among other initiatives in the world, agroforestry ranks high since over the last few decades. Today, tree covers reach nearly up to 10% from a billion hectares of agricultural landscapes and in the predictable future, an estimate of 1.6 billion hectares areas of land globally are likely to be converted under agroforestry management [13].

At the global level, more than 10% of agricultural ecosystem are occupied by tree cover with nearly 560 million people, in relation to human occupying landscape on the farm, this correspond to 31%. According to the World Bank report [14], statistics of the rural people that practiced agroforestry currently on their farms are approximately 1.2 billion. Total agricultural land around the world is 22,183,204 km2 amongst them 10,120,000 km2 have more than 10% tree cover, 5,960,000 km2 have more than 20% tree cover and only 1,670,000 km2 have more than 50% tree cover. This corresponds to 46%, 27% and 7.5% cover on agricultural land respectively. Because of the fact that tree cover ranges from zero to high, choosing certain tree cover as a percentage on behalf of 'agroforestry' is not ideal [15]. Trees with low canopy cover are economically important components that are integrated with crops in farming areas. Silvoarable farming, improved fallow, silvipasture, riparian buffer strips, shifting cultivation and multipurpose trees among others are

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the most common practices of agroforestry system [16]. Many authors have attempted to estimates the extent of agroforestry based on particular systems as presented in the Table 1.

TABLE 1

Estimates on the world agroforestry extent and their practices.

Regions	Practices	Estimated area (Million ha)	References
Africa, Asia and the America	Agrosilvopastoral, agropastoral and silvopastoral	584-1215	Dixon (1995)
South and Southeast Asian	Homegardens	8.0	Kumar (2006)
USA	Silvopasture, alley cropping, windbreaks and riparian buffers	235.2	Nair and Nair (2003)
Europian	Silvoarable agroforestry	65.2	Reisner et al. (2007)
World	All agroforestry system	400	Watson et al. (2000)

The multiple task of agroforestry system includes rising the economic status of the farming community, efficient resources utilization within the farm and environmental resilience to climatic change [17,18]. But yet, statistical agroforestry estimates are not readily available despite its high practices in tropical countries and other parts of the world [19]. Montagnini and Nair [20] noted that with gross diversities expected from trees species, soil attributes and stocking levels the estimates on extent of the area is an insurmountable task, particularly with respect to C stocks in agroforestry. Lack of appropriate procedure for delineating the area covered by mix stand of trees and crops is one of the most difficult tasks in estimating the area under agroforestry. In the concurrent systems, other systems that could be considered as agroforestry includes; shaded perennials, home gardens as well as intensive tree intercropping.

Nonetheless, where spacing or density is not properly considered in planting agroforestry component especially the trees, most of the systems are quite extensive (such as in the parkland system and extensive silvopastures). Consequently, in the case of windbreaks and boundary planting practices, the problem is worse, though the inter-row spacing between planted trees are relatively wide (e.g. windbreaks) or surrounding agricultural or pastoral plots (e.g. boundary planting), this is because trees extends quite over a larger area than the extent of perceivable areas [21]. Obviously, determining area under agroforestry is a daunting task; however, realizing the unlimited benefits derived from the system, it is worse to be done in an intensive progress.

CLASSIFICATION OF AGROFORESTRY SYSTEM

Agroforestry systems classification is a multifarious task due to the fact that some criteria need to be taken into consideration. Several classification has been proposed by scientists depending on the diversity and composition of both trees and crops/animals species adapted to a local condition. For examples, according to Sinclair [22] the term 'practice' should be more appropriate rather than the term 'system' as unit of classification, when considering similar practices in a different types of agroforestry, and that the practices with the same prospect for management and ecology can be considered together. Another classification is the Nair [23] guidelines where he suggested that outstanding to the intricacy in classification of agroforestry, no single classification is considered universal, and it can only be performed using several criteria and directed towards a particular goal. In this context, Nair [24] has classified agroforestry systems based on the systems and approaches which are more valid and accepted globally (Table 2). In this context, agrisilvicultural (agronomic crops+trees and shrubs crops), silvopastoral (pasture crops+trees) and agrosilvopastoral (crops+pasture crops+trees) are three important classifications of agroforestry system. Alternatively, apiculture with trees, multipurpose tree lots, aquaculture in mangrove areas among others specialized agroforestry system can separately be specified. The fundamental of agroforestry classification into three main types can conveniently be used to other terms as a prefixin an attempt to group or identify agroforestry system based on their basic components Reifsnyder and Darnhofer [25]. Agrisilvicultural system for example can be used for production of food, silvopastoral system can used in commercial farming in low land sub-humid or dry tropics for fodder and food productions, agrosilvopastoral system can be used in highland humid tropics for production of food and conservation of soil etc. Hence, it appears compatible, logical and practical to admit that the basic principle in agroforestry system classification is to admit the nature of its components.

TABLE 2

Major agroforestry classification approaches based on the systems and approaches (Nair, 1985)

Classification of the system based on their structure and function			Classification according to their spread and management	
Structure Nature and arrangement of the components especially woody ones		Function Role and/ or output of components, especially woody ones	Agro-ecological environment	Socioeconomic and level of management
Nature	Arrangement		Variables	Variables
Agrisilviculture (i.e. integration of trees and crops incl. shrubs)	Spatial (in space), homegardens (mixed dense)	Productive function -Food -Fodder -Fuelwood -Other wood -Other product	Variables	Variables
Silvipastoral (trees and pasture/ animals) Crops, Pasture/ animals and trees)	Mixed sparce (most system of trees in pastures) One tree in a width of strip)	Variables	Variables	Variables
Others (such as trees with apiculture, aquaculture, multipurpose trees lots etc).	Boundary (trees on edges of fields) In time (temporal) Concomitant Interpolated Sequential (separate) overlapping	Protective function -Windbreak -Shelterbelt -Soil conservation -Shelter -Soil improvement -Conservation -Moisture conservation -Shade (for man, animal and crop)	Variables	Variables

AGROFORESTRY FOR SOIL IMPROVEMENT

Recently, an interest in examining the quality and health of the soil has been rehabilitated as agricultural sustainability indicators. In the tropics and temperate part of the world, the practices of agroforestry has been enhanced for their have been promoted for decades both in the tropics and temperate regions of the world for their apparent benefits for providing ecosystem services besides improving soil quality [26,27]. Most of these benefits perceived from agroforestry could only be realized if the productivity and health/quality of the soil is maintained over a long run [28]. For thousands of years, farmers in the tropical countries are aware of the multiple tasks derived from trees and since then have secured, planted, designated and domesticated trees [29]. Competition and facilitation for the essential nutrients elements is expected to be high particularly in a mixed system of agroforestry were different functional groups of plants exists [30]. Similarly, in the tropics, efficient recycling of nutrients resources through facilitative role of trees in agroforestry system is well understood. As the soil's health and capacity to sustain production services depends on these availability essential elements.

Many scientific studies have proved the potentials of agroforestry system for the enhancement of both fertility and sustainability aspect of soils. For example, a field study was conducted in Zambia to evaluate the nutritive potential of intercropped tree crop (*Faidherbia albida*) with maize crop. The study revealed that more than 18 kg N ha^{-1} year-1 could be obtained from the litter inputs F. Albida with an increase in diversity and abundance of soil microbes [31]. Another experiment to compare the effectiveness of N-supply for maize utilization from the tree leaves of *Acacia auriculiformis, Baphianitida, Albizia zygia, Azadirachta indica, Senna siamea, Senna spectabilis, Tithonia diversifolia, Gliricidia sepium* and *Leucaena leucocephala* were conducted in Ghana. It was found that nearly 93 mg N kg^{1} could be supply from the tree leaves. Similarly, the leaves differed between the species in the rate of mineralization and nutritive contents, with the best maize yield improvement from *T. diversifolia* and *G. sepium*. However, the nutrients being organic in nature cannot be directly assimilated all by plants. Therefore, for the crop yield improvement, speciation of nutrients in soil is a key factor. Microbial activity directly influenced nutrients availability and this can vary with the designed system [32]. A study between two silvopastoral systems to compare organic matter accumulation and nutrient availability was conducted in Brazil; the two systems are *Eucalyptus grandis* and *Zeyheria tuberculosa*. The study showed that the essential nutrient elements (both macro and micro nutrients) were found higher in plots planted with *E. grandis* compared with the plot planted with *Z. tuberculosa* [33]. Hence, a rich microbial diversity can be assured in agroforestry that are key to soil health and productivity. Therefore, agroforestry practices could significantly offer great promises for the tropical soils in terms of fertility and quality improvement in a long run.

AGROFORESTRY FOR FOOD AND INCOME SECURITY

Agroforestry system has been recognized as a sustainable land use management option within the scientific and development communities that could put the end of critical global challenges currently facing the planet in terms of food security. For example, in India, the livelihood of the population can be improved through long agroforestry could contribute to livelihoods improvement in India where people have accumulated long history and local knowledge of agroforestry [34]. The ethno forestry practices in India and trees growing based on indigenous knowledge systems have been particularly recognized. The yield of annual crops can be enhanced by intercropping *Prosopis cineraria* in Rajasthan, at recommended density of 278 trees ha^{-1} at 6 and 7 years, 208 trees ha^{-1} at 10 years and less than 208 trees ha^{-1} at 11 years of age tree [35]. The study from different agroforestry models to determine the Net Present Value (NPV) on six year rotation was conducted in Haryana, the study revealed that the variation in NPV ranges 'between' Rs. 26,626 to 72,705 ha^{-1} yr^{-1} while 94 to 98% and 2.35 to 3.73 was obtained as the internal rate of return and benefit: Cost ratio from the study respectively. Further, according to the study of Dagar [36], reported that, yield increase of 2.15 t ha^{-1} in the plantation field of wheat grains was obtained as compared to the yield of the untreated fields of 0.64 t ha^{-1}. An increased in Rs. 72 000 ha^{-1} was earned by farmers from a field study conducted for a period of five years and four month in rotation resulting in 3.5:1 as a benefit: cost ratio at 12%. Hence, agroforestry can significantly influenced the overall development of a nation besides uplifting farmer's socioeconomic status Kumar et al. and Pandey et al. [37,38] suggested from experiment involving *Azadirachta indica* and *Phaseolus mungo* as understorey crop that despite the decrease in tree canopy, the wood volume and fruits yields of *A. indica* increases. Thus, resulting in higher economic returns. Similarly, pressure on natural ecosystems can be reduced through an increased in commercialization and production of valued products from domestication of such valued trees species [39]. In the tropics, improvement in economic security and nutritional status of poor people can be achieved by domestication and sustenance of fruit trees and other valued species in agroforestry (Milne et al. and Pandey et al. [40,41] reported that, the availability of wood products in agro-ecosystem may be improved through suitable agroforestry programmes, this can upgrade developing countries chance to partake in the growing global economy. Thus, agroforestry promise the food and nutritional security along with enhancing income for maintaining livelihood security of the poor farmers [42].

AGROFORESTRY FOR CLIMATE CHANGE MITIGATION

Climate change scenario is a well-known global challenge influencing every sector of human life, agriculture is also included [43]. Farmers, especially the small holder producers, are at the last resort of climate change and their livelihoods are frequently at risk due to unstable and fluctuating crop productivity, in addition to deterioration and loss of natural resources. To stop climate from changing it seems to be a difficult task, but however, many effort can be attempted by devising adaptation mechanisms to lessen its magnitude and effects [44]. The extent and months of growing season can both influenced the occurrence and response of trees growth as consequence of modified climate change [45]. Since after the industrial revolution, atmospheric CO2 and climate change upsurge [46]. Average CO2 concentrations prior to industrial revolution estimated at 270 ppm, presently exceeded 380 ppm, and by the middle of the century, predicted to surpass 550 ppm. Concentration of CO2 in the atmosphere contributed to the effects of greenhouse phenomenon for more than 60% that is driving global warming upon associated with vagaries in weather pattern and precipitation, and ultimately have a negative impacts on agricultural production [47].

Trees play a vital role in the battle against changing climate by sequestering carbon and providing a range of other services. Combating climate change through agroforestry and ensuring that rural communities benefit from, and protect environmental services are key components of several major projects. By adopting agroforestry practices, smallholder farmers have been able to attain their nutritional requirement, while turning more resilient to the impact of climate change [48]. "Priority tree species were identified in Burkina Faso and Sierra Leone, and improved tree germplasm made available to farmers by the rural resource centers established through the project. Agroforestry system is in fact considered to perform the two functions; as a sink and source of atmospheric carbon [49]. However, certain factors such as the type of system adopted in agroforestry, nature of tree species, soil condition, climate conditions, as well as management practices quite influence C sequestration potential depending on the region. Overall, in the tropical agroforestry systems, the rate of soil C sequestration is relatively higher than in arid/semiarid or temperate environments [50], consequently, the lacking segment is the comprehensive meta analyses. Soil carbon sequestration rates in the tropics and subtropics in the range of 0.1 and 4.2 Mg ha1 per year have been reported Lorenz and Lal, Oelbermann et al., Nair et al. [49,51-53] documented that agroforestry has been recognized as greenhouse gases mitigation option under the Kyoto Protocol's Article 3.3, A & R (Afforestation and Reforestation). Thus, the levelled of awareness increases spontaneously for the potential of agroforestry in C sequestration [54].

CONSTRAINTS FOR TROPICAL AGROFORESTRY SYSTEM

Although there is wide gap in comparison from place to place, the maintenance and or integrating trees on agricultural landscape were originated in the early around the world and play an essential role in terms of land management. As the time goes when the world populations are continuously increasing, practice such as monocropping becomes more common, in an attempt to meet food demand of the teeming population. This practice started only during the last century and presently getting more intensified in the tropical regions. Delayed return on investment, under-developed markets, emphasis on commercial agriculture, limited awareness of the advantages of agroforestry, unclear status of land and tree resources, adverse regulations and lack of coordination between sectors etc. are the certain factors that limit agroforestry productivity in the tropics (FAO 2015) [56].

POLICY AND GOVERNMENT

A tremendous change in terms of productivity and sustainability of agriculture was observed since late 1970s after the word "agroforestry" was coined. With the participation of international development community during this period, most of the rural poor attention was drawn. Moreover, introduction of Green Revolution associated with social and environmental side effect were starting to be felt though brought tremendous rise in crops yields particularly cereals crop. Many stakeholders recently meet to develop alternatives, by practices like intercropping and integrating trees and animals on the same field. As a result, International Centre of Research on Agroforestry (ICRAF) was created by the international development community as an indication of agroforestry's recognition as an important land use practice worthy intensified research [57]. Through this research, modern science can be applied to improved already existing local practices (FAO 2015) [56].

Government and private institutions recognition to agroforestry practices is becoming further extensive. The government of Philippines for example, considered agroforestry for rural development as a viable strategy since in the early days, therefore, they are among the top to support agroforestry. More recently, Indian government in 2014, adopted a policy called a National Agroforestry Policy. Thus, most of the developing countries express their commitments through institutionalization for support wider adoption of agroforestry. Diverse benefits of farm trees and agroforestry system was also recognizing by the government of New Zealand and Australia. Landcare and the Sustainable Farming Fund through their respective programs were initiated, as a path to enhanced agricultural practices towards a more sustainable manner, integrating trees on farms is seen as a best alternative, particularly with agroforestry projects. Generally, tropical countries increasingly recognized land use practices benefits of agroforestry and is thus becoming more widespread. The initiation of modern agroforestry is thought to finds its roots in the solutions to development problems; the impact derived has now been realized even in the developed countries with different policies and support from the government [58,59].

CONCLUSION

Agroforestry is a promising enterprise particularly in these days of constantly changing climate and vigorous population increase in terms of food demand. Most of agroforestry system provides several services to the farming community such as fuel wood, furniture materials, foods/fruits, medicinal herbs, animal feeds and microclimates among others and maintains the productivity of both trees and crops/animals in a sustainable manner through efficient recycling of resources. However, these benefits only become realistic with proper management skills and/or suitable combination of the systems components. Consequently, lack of efficient management strategies between the trees and crops/animals in the system is the major constraints that turned the system underappreciated and underexploited. As such, more research will; therefore be needed to clearly understand the suitability of trees and crops/animals combination based on climatic condition as tropical countries are characterized with diverse type of climates. Government and other private institutions intervention and encouragements by adopting several policies are a key player in exploiting the potentiality of tropical agroforestry system in any given locality.

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